To: Pebb community

From: Vic Temple

Subject: Soft Switching trip report   pebb/reports/minnsum.doc,vakt,9-29-98

MCT's can play an important role in soft switching.

This trip was well worth the effort. I saw some of the latest in soft switching circuits which, for the purpose of Pebb applications, boiled down to two classes, one in which the current di/dt was always limited by a converter inductor and one in which the converter current response was nearly instantaneous. In the first class, generally, current controlled converters, MCT's could play a large role in both main and auxiliary switches. In the second class, generally voltage controlled, the issue of how to deal with system shorts has to be dealt with if MCT's are used as main switches.

Both of these converter types made generous use of auxiliary switches whose short, high current pulse use virtually demands using MCT's. All auxiliary switches could be implemented with a small (if MCT's are used) ac switch or a small half bridge. One presenter showed that an ac switch built with independent antiparallel current paths (ie no center point tie) reduces the effect of diode reverse recovery.

The bottom line was that MCT's could well play a role in making soft switching affordable by reducing cost and minimizing the dissipation of the auxiliary circuitry.

All circuit and device choices boil down to cost and reliability. Other parameters are "secondary".

The conference had very useful breakout sessions on power supplies, industrial, aerospace and automotive applications. Generally power supplies were more likely to be soft switching as were all applications with a premium for small size and high efficiency, eg laptop power supplies. Least likely to be soft switched were DC-AC drives with very wide load ranges such as automotive.

Many lists of trade-offs beyond the cost/reliability ones which I listed above were considered independently such as efficiency, EMI, size/weight etc. In my view these are merely factors that enter the cost and reliability value equations at either system or sub-system level. In fact, all the subordinate (in my mind) issues boiled down to considerations of
1. efficiency,
2. complexity or
3. special constraints on size/weight or through standards such as EMI.

Even size and weight which are important considerations in aerospace and in vehicles are, at bottom, issues best viewed by their overall system impact on cost and efficiency.

Comments on cost:

Of all the basic issues affecting cost, efficiency is the largest. Inefficiency at maximum rating (ie losses) divided by thermal impedance sets the size and cost of the power devices and the cooling system. At average run rate it impacts operating cost.

Soft switching complexity increases control component number and nominal complexity but not necessarily cost, provided the new components can be simplified due to reduced noise immunity requirements. This was the case for the PMCT/NIGBT main switch module and NMCT/PMCT auxiliary switch modules I showed at the conference.

Under "special constraints" the standards referred to above include EMI. It was shown that many of the soft switching circuits had far superior EMI characteristics that come from controlling turn-on di/dt and/or turn-off dv/dt. Soft switching could often be implemented with lower overall volume due to smaller L's and/or C's. Aerospace and vehicle applications emphasize the system cost value of low size and weight.

Comments on reliability:

Again the highest impact on power device reliability is efficiency through its effect on junction temperature. Average efficiency translates into average junction temperature with, for each 10C reduction, leading to about a factor of two improvement in blocking voltage life. Switching losses in the power device (ie switching inefficiency) has a major impact on semiconductor failure. Here the mechanism is the internal silicon stress caused by very rapid, adiabatic temperature increases that occur when switching. The failure is known as di/dt failure and the given cycles to failure is be proportional to (~300/dT) to the 9^{th} power. Soft switching, which may typically reduce switching losses a factor of 2 to 5 would virtually eliminate di/dt failure and, if switching losses dominated conduction losses, could well improve blocking voltage life by an order of magnitude or more (eg Tj reduce by about 30C).

In my mind the major negative issue to be addressed here is complexity. More switches have to be correctly driven and, usually, at a several times higher frequency. Driving more switches does not mean a great deal more complexity if the timing relationship between main and auxiliary devices is simple. Nor does increased computation greatly impact cost. The problem in systems I have seen has predominantly been the misfiring of devices due to noise introduced on the control and gate drive by power device switching. This type of misfiring is largely eliminated by referencing the gate drives to potentials that, in theory, do not change potential during switching. This requires switches like the PMCT for the plus bus referenced devices, for example. Since no p-type switching device has a completely square SOA this solution requires at least a snubber circuit which fits in better with soft than with hard switching.

Use of high side switches also reduces the number of required floating power supplies as well as their performance requirements. Our projected ARCP needs only three (plus, minus and mid) while a hard switched drive that may not be able to use a p-type semiconductor switch would require a low side supply and 3 supplies that switch at the order of 5 KV/us at each phase point.

The second most likely source of misfiring is noisy sensor measurements. This can be addressed by limited frequency response (and much less expensive) current sensors. For precision timing voltage sensors accurate to no better than 10 to 20% of the bus voltage are sufficient to establish device switching time to within a fraction of a microsecond. Using this approach and simple, locally tying the main and auxiliary gate timing is sufficient to inexpensively and reliably gate soft switched device modules.

What can Pebb device and module developments offer?

A menu of devices that help optimize soft switching including:

- Device choices

1. NIGBT's for main switches that require fast current limiting
2. NMCT's for main switches that do not require fast current limiting (reduces conduction and switching losses)
3. PMCT's for high side switches where turn-off is softened by snubber or by auxiliary switching (reduces conduction losses and noise/cost of upper switch implementation)
4. N and PMCT's for all forms of auxiliary switches. (several fold reduction in auxiliary switch cost/losses)
5. As a small (5A) device size so far, a device is in either MCT or IGBT mode depending on the value of voltage on 2 independent gates.

- Modules built for soft switching

1. single phase with built-in ac or phase topology auxiliary switches
2. full bridge with built-in ac or phase auxiliaries
3. 3-phase bridge with built-in ac or phase auxiliaries

4. with optional temperature sensor
5. with optional on/off voltage sensor
6. with optional gate drive buffer

- ThinPak package option with
1. extremely low parasitics (L<3 nH)
2. extremely low height, footprint and weight
3. known good switch fabrication method
4. more uniform module current flow
5. potentially lower module cost

- Cooling options including:
1. standard cold plate attachment
2. bonding to AlSiC heat spreader and exchanger at >2x rating improvement
3. bonding to metal foam heat exchanger at additional 25% rating improvement and potential cost reduction

- Gate drive IC with
1. +/- 15 voltage range
2. regulated on-chip plus and minus 5 volts supplies for reference and for powering power node logic
3. latch and reset channels for reliability enhancements
4. over-temperature sensor
5. high gain amplifier to simplify current sense implementations
6. minimum on and off-time specification
7. high noise rejection comparator inputs
8. ability to source and sink opto-coupler currents
9. 0.1 to 2.0 ohm output impedance available
10. low I/O delays despite high gain

Summary:

Soft switching holds out the possibility of both increased reliability and reduced cost in more than 50% of the applications now done with hard switching provided we recognize that a snubbered device is a soft-switched device.

The main reason that soft switching is now mostly concentrated in few kilowatt or lower power supply applications is because:
- the high cost and perceived reliability of controls (and sensors) as currently implemented. The sensor approach and the availability of a p-type power device will allow a several times lower cost and many times more reliable control.
- The availability of appropriate auxiliary switches.
- The availability of appropriately packaged and tested soft switch power modules, in particular modules including pulse current optimized auxiliary switches.

The device, packaging, cooling and gate drive advances of the Pebb program will result in expected device cost reductions and reliability enhancement in line with lower average and peak power requirement of soft switching.

Gate drive cost and control reliability will be enhanced by using qualified high side switches and by properly considering the reliability impact of our sensor approach.